Grass, legume, and cereal silages for ruminants

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L. J. Fisher
Research Station, Agassiz, B.C.

J. A. Robertson
Research Station, Melfort, Sask.

P. Savoie
Research Station, Sainte-Foy, Que.

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CONVERSION FACTORS FOR METRIC SYSTEM

Imperial units	Approximate conversion factor	Results in:	
LINEAR			
inch	x 25	millimetre	(mm)
foot	x 30	centimetre	(cm)
yard	x 0.9	metre	(m)
mile	x 1.6	kilometre	(km)
AREA			
square inch	x 6.5	square centimetre	(cm^2)
square foot	x 0.09	square metre	(m^2)
acre	x 0.40	hectare	(ha)
VOLUME			
cubic inch	x 16	cubic centimetre	(cm^3)
cubic foot	x 28	cubic decimetre	(dm^3)
cubic yard	x 0.8	cubic metre	(m^3)
fluid ounce	x 28	millilitre	(mL)
pint	x 0.57	litre	(L)
quart	x 1.1	litre	(L)
gallon	x 4.5	litre	(L)
WEIGHT			
ounce	x 28	gram	(g)
pound	x 0.45	kilogram	(kg)
short ton (2000 lb)	x 0.9	tonne	(t)
TEMPERATURE			
degrees Fahrenheit	(°F-32) x 0.56 or (°F-32) x 5/9	degrees Celsius	(°C)
PRESSURE			
pounds per square inch	x 6.9	kilopascal	(kPa)
POWER			
horsepower	x 746	watt	(W)
	x 0.75	kilowatt	(kW)
SPEED			
feet per second	x 0.30	metres per second	(m/s)
miles per hour	x 1.6	kilometres per hour	(km/h)
AGRICULTURE			
gallons per acre	x 11.23	litres per hectare	(L/ha)
quarts per acre	x 2.8	litres per hectare	(L/ha)
pints per acre	x 1.4	litres per hectare	(L/ha)
fluid ounces per acre	x 70	millilitres per hectare	(mL/ha)
tons per acre	x 2.24	tonnes per hectare	(t/ha)
pounds per acre	x 1.12	kilograms per hectare	(kg/ha)
ounces per acre	x 70	grams per hectare	(g/ha)
plants per acre	x 2.47	plants per hectare	(plants/ha)

Contents

Introduction

The purpose of this bulletin is to describe in detail the ensiling process, its advantages, its disadvantages, and the management costs and skills required to make it an effective form by which to preserve and utilize forage nutrients. It is hoped that this basic information will be helpful to farmers and extension workers when evaluating a silage system within a given farming enterprise. Ensiling forage crops is one of several methods of preserving nutrients for feeding ruminants when they are housed indoors. Before you select a system of feed preservation, you should compare the advantages and disadvantages of the main systems available in your area such as high-moisture silage, medium-moisture or wilted silage, or hay.

Silage making—advantages and disadvantages

Silage making is an ancient art, but only in the past 20 years has it become a major method of forage conservation. It has been estimated that in 1968 only 12–15% of conserved grass was in the form of silage in the United Kingdom, but by 1979 this proportion had grown to 45%. This trend, which is also apparent in North America, is the result of an increased awareness of the losses that occur in the field because of multiple handling of forage during the natural drying process, and forage spoilage and leaching of nutrients caused by delays in harvesting after cutting due to inclement weather. Major losses can also occur during storage of hay if the moisture content at harvest was too high and/or the dried crop was not stored under shelter. The availability of mechanized feeding systems for silage has been a further important factor influencing the use of ensiling as a preservation technique.

Advantages of silage making are as follows:

1. When the hay crop is made into silage, the wilting period is reduced to a minimum and there is less chance of damage to the cut forage from weathering. Silage making effectively shortens the harvest period, and increases both the amount of crop that can be harvested when it is at its optimum nutrient content and the time available for subsequent regrowth. This advantage becomes even more important for annual crops that mature in late summer, when conditions for field drying become less favorable than in June or July.

2. Modern intensive livestock enterprises require large quantities of feed and ensiling is an excellent method of harvesting crops at their optimum nutrient content over a period of several months. This is done by carefully selecting perennial grass–legume mixtures, and annual cereals varying in dates to maturity, and by varying dates of seeding annuals.

3. Silages require no further processing, can be mixed uniformly with other feedstuffs, and are readily handled by mechanical feeding equipment.

4. Ensiling is a suitable method for salvaging hail-damaged or frozen crops. Weedy crops can be harvested before the seeds scatter.

5. Wastage at the feed bunk is reduced.

6. The fire hazard is negligible insofar as the forage used to make silage is not too dry (more than 60% dry matter).

Disadvantages of silage making are as follows:

1. Ensiling requires specialized storage structures. However, bunker silos can be used for equipment storage and upright silos can be used for grain storage.

2. Silage has a limited bunk life once it is removed from storage. Molds develop if silage is exposed to the air for several days. For that reason, it does not lend itself to off-farm sales. Because of its high moisture content, silage is also more expensive to transport than hay.

3. Dry matter intake is generally lower than in animals on pasture or receiving green chopped forage or hay.

4. If ensiling management is inadequate, storage losses can offset the advantage of reduced field losses.

5. There is a high labor requirement during harvest to ensure rapid filling of the silo.

6. Investment in machinery is relatively high.

7. Silo gas is a health hazard. Silo gas, nitrogen dioxide, is a toxic gas produced the first few hours after ensiling. It is most likely to be present at dangerous levels when crops containing high levels of nitrate nitrogen are ensiled. Because nitrate accumulates in the vegetative part of the plant and not the seed, immature whole plant cereal silages or grass-legume silages produced on highly fertilized land are most commonly the source of silo gas. Should it be necessary to enter an upright silo shortly after filling, always ventilate the area above the silage by turning on the blower fan and opening any doors. Have someone present outside the silo in case assistance is required, and wear a safety harness and lifeline.

What makes silage different?

Silage can be a feed of uniform and excellent quality. If improperly prepared it can also be variable and inconsistent in quality, and thus reduce animal performance. Silage quality is affected by a number of interacting factors which control the fermentation process. These factors are as follows:

1. Stage of maturity—alters soluble carbohydrates, protein, and fiber contents.

2. Moisture content—controlled by stage of maturity, weather conditions, and harvesting system.

3. Species of forage.

4. Type of silo.

5. Packing and sealing procedures—influenced by fineness of chop, moisture content, speed of filling, and additives.

6. Utilization—silages require different supplements and allow the use of different feeding systems.

This complex interaction of the factors controlling silage quality can be used to advantage if the following four essential conditions are ensured:

1. Air exclusion. An anaerobic environment is required for successful fermentation. The palatability and feeding value of the recovered material are reduced if air is allowed to enter the silage mass during the fermentation process. Common causes of air entering the silage are crops ensiled when they are too dry for firm compaction, and poor chopping because of dull knives or improper setting, characterized by large and uneven particle sizes. Air can also enter the silage as a result of insufficient packing, porous side walls, inadequate sealing, or improper operation or mechanical failure of an airtight silo.

2. Rapid increase in acidity. A rapid increase in acidity can be accomplished by ensiling crops with a high soluble carbohydrate content, by adding readily fermentable material, or by using acids to increase acidity. High acidity is needed to encourage a lactobacillus type of fermentation and the production of optimum levels of lactic acid. It also inhibits a clostridial type of bacterium that produces butyric acid and a foul smelling silage, which causes a low dry matter intake. Acidity is measured according to the concentration of hydrogen ions in a solution. The pH, which is inversely proportional to this concentration, ranges from 0 for highly acidic solutions to 14 for highly alkaline solutions. Green forages are slightly acidic at the outset with a pH of about 6.0. A well-fermented silage is acid, with a pH of between 4.0 and 4.5.

3. Moisture content. Moisture content is the most important factor in determining how the forage crop will react to the ensiling process. When at optimum nutrient content, grasses may contain only 15% dry matter and cereals 45% dry matter, the importance of regulating moisture content at ensiling time either by wilting or by adding water can be appreciated. If silage is very moist (less than 30% dry matter), acidity increases slowly and fermentation lasts longer, resulting in a wasteful amount of acid production and protein breakdown. For grasses, legumes, and cereals ensiled in bunker silos or in structures other than oxygen-limiting upright silos, a more stable fermentation and higher dry matter intake are achieved by ensiling material containing between 30 and 40% dry matter. Ensiling material that is too dry usually results in inadequate packing. The material then heats up excessively, so that the proteins become fixed and unavailable to animals. The result is a silage that has high crude protein content on analysis but does not provide the proteins required for milk or meat production.

4. Sufficient population of lactobacilli. Usually there are enough of the lactobacillus type of bacterium present on the grass to produce lactic acid if fermentable material is available. Activity of the bacteria can be restricted by too much air, by too mature or dry a material, or by a very wet cold forage, resulting in a poorly preserved silage of low palatability and short bunk life.

In order to effectively control the many factors influencing silage quality, one should be aware of the various stages of the fermentation process.

First, there is the continued respiration of plant cells, which produces carbon dioxide and utilizes oxygen caught in the silo mass, thus encouraging the onset of anaerobic conditions. This phase is shorter in upright silos than in bunker silos and is less when filling is rapid, ranging from 5 to 15 h. Extended surface exposure favors growth of molds and yeasts. There is a considerable breakdown of plant protein into nonprotein nitrogen and the generation of excessive heat. If the heat exceeds 35°C, it can reduce digestibility of the protein and carbohydrate portions of the forage, resulting in a heat-damaged silage.

Second, there is a period of acetic acid production by coliform bacteria, which is short-lived and terminated by the rapid drop in pH.

Third, lactic acid production begins through the proliferation of lactobacilli and streptococci bacteria. The more rapidly the silage enters the lactic phase of fermentation the lower will be the energy losses and the higher the nutrient content of the silage. This phase should be reached within 2 or 3 days. Lactic acid content should increase to between 4 and 5% of the silage dry matter, the pH should drop to a range of 4.0–4.5, and if air is kept out, no further fermentation should occur.

A fourth stage of fermentation may occur if acidity is not high enough to prevent the action of clostridial bacteria in converting the remaining soluble carbohydrate and lactic acid to butyric acid. This is a deteriorating phase of fermentation which begins approximately 8 days after ensiling, and results in the production of ammonia from protein and losses of energy in the form of carbon dioxide and heat, especially if the ensilage is not properly packed, inadequately sealed, or too high in moisture content.

A fifth stage of fermentation may occur when silages are removed from the silo for feed; this stage is more predominant in drier silages and in silages that have a relatively low acid content. In this stage, the growth of molds and yeasts results in heat production, a reduction in digestibility, and, most important, a decrease in palatability, sometimes as the result of toxins from molds or fungi. The loss is most obvious on the surface of silos that are being fed out too slowly in warm weather.

In summary, the fermentative process of ensiling is a rapid production of acid, dependent on the establishment of anaerobiosis in the silo, which is influenced by the moisture and soluble carbohydrate contents and the buffering capacity of the forage.

Structures for storing silages

There are several basic designs and variations to chose from when selecting a suitable silo structure. The choice depends on the resources available and the feeding system with which it is to be coordinated. Each type of silo has its own limitations as to the moisture content of the crop to be ensiled. Structural damage caused by acids and excessive runoff occur when forages that contain more than 75% moisture are ensiled in tower silos. Conversely, bunker silos are better adapted to high-moisture silage but require careful packing and sealing if moisture content is less than 65%.

For a given degree of management skill, ensiling losses are inversely related to the capital cost of the structure (Table 1). Dry matter losses depend on the expertise and care taken in storing silage.

TABLE 1 Range of dry matter losses as a percentage of dry matter ensiled that can be considered normal for various types of silos and levels of management

Type of silo	Normal moisture range (%)	Field losses (%)	Storage losses percent Management skill High	Low
Oxygen-limiting tower	40–60	6–12	3	8
Concrete tower	55–70	3–9	5	15
Bunker, horizontal	60–85	2–8	9	20
Earth, horizontal	60–85	2–8	12	25
Covered stack	60–85	2–8	15	40

Another consideration when selecting a suitable silo structure is the relative annual cost per tonne of dry matter stored. Appendix A provides a cost calculation for three types of silo structures. Costs depend primarily on the outlay required, interest rates, and dry matter losses. Since these factors vary over time and according to region, costs must be calculated for each specific situation.

The many advantages and disadvantages of each type of silo structure should also be considered when making a selection. A type of silo suitable for one farm may not be suitable for another. A skilled operator may be able to use a low-cost silo structure effectively, whereas an unskilled operator may need an expensive structure to obtain the same results.

The following is a summary of some of the factors that should be considered when selecting a suitable silo.

Horizontal, or bunker, silo This type of silo provides the lowest initial capital cost, particularly when large tonnages are concerned, and can be constructed using on-farm labor and equipment. The horizontal silo is suitable for large-volume harvesting and feeding systems. It can be adapted to self-feeding by using a feeding gate or an electric wire, especially if a paved floor and apron are included; however, self-feeding restricts the depth of the packed silage to approximately 2 m. This type of silo is most suitable for high-moisture direct-cut silage, because effluent losses are less than for silages stored in tower silos at the same moisture content. Field losses and cost of equipment operation may be lower for bunker silos if forage cutting and chopping can be done in one operation. Greater management skill and time are required to keep dry matter losses to an acceptable level (< 10%), than for tower silos, particularly with higher dry matter silages. Labor and equipment required for filling and unloading silage for feed are usually greater than for tower silos, as are space requirements for the silo and access roads. Drainage and drifting snow must be considered when planning the placement of

a horizontal silo. Horizontal silos may be filled by blowing in or dumping the forage and then packing it with a tractor. The ensiled material can be removed from horizontal silos using a front-end loader or a reel-type unloader or they can be equipped for self-feeding systems.

Tower silo The conventional-type silo may be built of wooden or concrete staves or cast in place concrete. Oxygen-limiting tower silos may be either glass lined or constructed of aluminized steel or concrete and can be equipped with either bottom or top unloaders. Tower silos are easily adapted to mechanized feeding systems, have lower dry matter losses, and require less space than horizontal silos. In conventional tower silos with top unloaders, the silage on the surface is continually exposed to the air. The best results are obtained when the forage ensiled contains 30–40% dry matter and at least 5–10 cm of silage are removed every day. Oxygen-limiting silos reduce air contact with the silage and allow continuous throughput of forages because they unload from the bottom. They have lower losses than conventional types but are more expensive to build and operate. A longer wilting period is generally recommended for forage before it is put into oxygen-limiting silos. The dry-matter content should range from 40% to 55%. This requirement can be a disadvantage in areas where there is a high risk of rainfall at harvesttime for forage harvested at its optimum nutrient content. If the silage in tower silos has a high moisture content, freezing can be a problem at removal time. Regardless of the type of structure used, the quality of the fermented feed can be no better than that of the material ensiled.

Stack silo Covered stacks can provide adequate storage for surplus forage. The stacks must be located in a well-drained area, be built quickly, and sealed with a plastic sheet (15μm, or 0.006 in. thick) held down by tires, bales, or sand. Losses are lowest in areas of low temperature and low rainfall. The silage should be used during the cooler seasons. Stack silos have been used successfully in northwestern Quebec as an effective storage system for grasses. Stack silos are a low-investment form of storage but require good management to prevent excessive losses during storage and feeding.

Bagged silage The costs of a bagged silage storage system are high but if the plastic bags that are used in this system are kept sealed they do provide excellent control of fermentation. The system has the flexibility required for custom work where relatively small tonnages are involved. Repairs and upkeep are minimal and silages with a wide range (20–50%) of dry matter content can be stored. This system has several disadvantages: it requires a large area for storage, there may be problems with snow and freezing temperatures, and the plastic bags cannot be reused. In older systems the time required for filling bags was considerable, resulting in a slower than average harvesting rate; however, recently developed prefolded bags have reduced the time required to perform this operation to a few minutes. Generally a bagged silage system unloads with a front-end loader but can be designed for self-feeding. Once the silo is opened, the silage should be used quickly to avoid losses from mold for silages in excess of 40% dry matter.

Baled silage Although several of the large balers can make high-density bales suitable for fermentation, some of the older models with pressure rollers can cause problems if high-moisture material becomes wrapped around the rollers. To make good silage the bales must be uniform and of even density, and the ideal dry matter range is 25–35%. Thorough sealing of the stacks is essential, because otherwise mold can grow around the edges of individual bales. If bales are not dense, serious heat damage and dry matter losses can also occur. Bales should be used before the warm weather begins. The bales should not be more than 1.2 m in diameter because of their high water content and greater density relative to hay. They should be stacked in a well-drained area with a minimum of air space between bales, covered, and sealed the same day. Once the seal is broken the silage must be used within a few days.

Silage additives

The wide range of results obtained during silage making shows the need for more reliable methods to ensure a more consistent quality. Although silage additives do help improve the quality of silage, it is important to know when they would be beneficial and when they would simply be an unnecessary expense. The main factor in deciding whether or not an additive should be used is the moisture content of the crop at ensiling time. Another factor is the kind of crop ensiled. It is generally accepted that additives do not improve the fermentation of corn silage but may assist fermentation in other crops. If we classify silages according to their moisture content, we have three main categories: high-moisture silage with a moisture range of 70–85%; wilted silage with a moisture range of 60–70% (55–65% in tower silos with a diameter greater than 6.5 m); and half-dry silage (haylage) with a moisture range of 40–60%. With high-moisture silage, the use of an acid-generating additive is recommended. Wilted silages benefit from an additive only if silos are not sufficiently airtight, or are not properly sealed, or if faulty techniques are used in making the silage.

Available additives—which ones should be used? A number of additives are currently marketed in Canada. The main types are acids, flavor compounds, antioxidants, bacterial cultures, enzymes, sterilants, antibiotics, and feedstuffs. Many of these types of additives have some beneficial influence on silage fermentation, but few can be classified as reliable additives producing consistently good results.

Feedstuffs such as molasses or grain increase the nutrient content of the silage and provide a source of fermentable carbohydrate which speeds up the fermentation process. However, some of the nutrients are lost during fermentation and this loss relative to the nutrient value of the feedstuff when fed directly to the animals must be taken into consideration. Feedstuffs such as beet pulp, dry grain, or chopped hay can be effective in reducing effluent losses and improving fermentation of high-moisture silage. Urea has been ensiled with corn silage (at approximately 4 kg/t) in order to increase its nitrogen content.

In recent years, a number of chemicals have been used to promote proper fermentation in the silo. Formic acid, at 2% (dry matter basis) or 3–4 kg per wet tonne of silage, has been used successfully in reducing pH and preventing secondary fermentation in high-moisture grass silages. For legume silages, 4–5 kg/t are required. Use of a pH-measuring device is recommended to ensure that sufficient acid is added to lower the pH of the forage to 4.2 without making it fall below 4.0. Because of the corrosive nature of this chemical, rubber gloves, aprons, and eye protection should be used by operators when they are mixing and filling applicators with formic acid solutions, and equipment should be washed after each use. Numerous studies in Europe, USA, and Canada have indicated that the addition of formic acid to unwilted silage (18–26% dry matter) has improved the nutritive value of that silage by $4–8 per wet tonne through an increase in the digestibility, intake, and efficiency of utilization of the forage. Formaldehyde has been used in combination with formic acid in order to protect the protein fraction of the forage from being degraded into nonprotein nitrogen. Propionic acid-based liquid preservatives have proven effective in reducing nutrient losses but can also be unpleasant to work with.

In order to take advantage of the benefits of quickly reducing the pH of the silage, yet eliminate the problems of working with corrosive liquids, various companies have developed additives in the form of powders. Livestock response to silages treated with these powder additives has been so variable that only a few additives are currently registered in Canada. These are lactic acid bacteria cultures—both viable and nonviable. The commercial additives can be classified into three categories: sodium metabisulfite salts, which are designed to react with the water in high-moisture grass to produce acid and lower the pH; mixtures of enzymes, which are supposed to stimulate fermentation and lactic acid production; and dried cultures of lactic acid bacteria, which stimulate lactic acid production.

Generally speaking, livestock response to silages treated with the additives in the last two categories is not better than the response to untreated silages, although some increase in lactic acid production and fermentation temperatures has been noted. The first category of additives described has been effective in reducing surface spoilage and improving palatability of high-moisture silages.

Silage additives should be considered on an individual basis. Response to the same additive has not been consistent. The quality of crop management and the stage of maturity, species, and dry matter content of the forage, as well as the type of silo used and the weather conditions can influence the effectiveness of additives.

When ensiling is done properly, the use of additives offers few advantages. The use of additives should be considered only when it is difficult to meet all the requirements for producing good silage. In Canada, wilting in high rainfall areas is undoubtedly the hardest requirement to meet and the use of additives should be considered as being potentially useful.

Equipment and harvesting conditions

Most field crops and certain waste products lend themselves to ensiling as a means of preservation. Palatability of poor feedstuffs tends to be enhanced by fermentation, whereas palatability of lush forages tends to be decreased. The ensiling process does not improve the nutritive value of the feed ensiled, regardless of the structure or additive used. It is therefore important that forage crops be harvested at their optimum stage of maturity and ensiled at an optimum moisture content.

As a guideline, grasses should be harvested just before head emergence with the exception of timothy, which should be fully headed, legumes at the bud to one-tenth bloom stage, wheat, barley, and rye at the firm dough stage of maturity, and oats no later than the milk stage of maturity. The species of crop selected depends on a number of circumstances such as growing conditions, soil, rainfall, crop rotation, type of animals to be fed, and equipment and facilities available for harvesting and preservation. Optimum harvesting time for grasses and legumes is often a compromise between increasing dry matter yield and decreasing digestibility. For lactating dairy cows, maximum digestibility is desirable, whereas for the maintenance of beef cows more emphasis would be placed on maximum yield. Data provided in Tables 2 and 3 give the approximate trends in nutritive value and yields that may be expected at various stages of maturity.

TABLE 2 The feeding value (dry matter basis) of legume forage as influenced by stage of growth at which it is harvested

Stage of growth	Total digestible nutrients %	Crude protein %		Dry matter intake Percentage of body weight
		Grass	Legume	
Vegetative	63	15.2	21.0	3.0
Boot or bud	57	11.3	16.4	2.5
Bloom	50	7.5	11.5	2.0
Mature	44	4.1	7.3	1.5
Regrowth	52	11.3	16.1	2.6

Source: Lovering, J. 1975. Effect of timothy maturity at harvest on feeder cattle ration costs. Can. Farm Econ. 10(2):25–32.

TABLE 3 The protein content and dry matter yield of timothy with increasing maturity

Days from first cut	Crude protein %	Dry matter yield kg/ha
0	15.9	5190
14	14.0	6270
28	10.9	8050
49	9.2	9780

Source: Lovering, J. 1975. Effect of timothy maturity at harvest on feeder cattle ration costs. Can. Farm Econ. 10(2):25–32.

Controlling the moisture content of the material to be ensiled is the most critical characteristic in making high-quality silage and yet it is the most difficult to control. Direct-cut grasses and legumes range from 14 to 18% dry matter, depending on stage of maturity, species, and weather conditions. Ensiling grass, legume, or grass–legume mixtures below 30% dry matter results in valuable nutrients being lost in effluents from tower silos (Table 4).

TABLE 4 Rate of flow (30 days) and chemical composition of silage effluent as influenced by dry matter content of the ensiled forage

	Effluent				
Silage dry matter (DM) %	Flow kg/day	Protein %	Soluble carbohydrates g/L	DM %	Ash % DM
15.7	972	0.72	16.4	4.42	18.9
17.0	408	0.82	19.8	5.06	18.9
20.0	380	1.12	15.5	6.78	17.9
24.4	166	1.42	26.5	8.40	15.4

Source: Fisher, L. J.; Zurcher, P.; Shelford, J. A.; Skinner, L. 1981. Quality and nutrient content of effluent losses from ensiled high moisture grass. Can.J. Plant Sci. 61:307–312.

If the ensilage is low in dry matter, secondary or clostridial fermentation frequently takes place, causing lower dry matter intake and reduced digestibility. Wilting is therefore necessary but it requires an extra field operation with subsequent cost and risk of dry matter loss. Ensiling below 60% moisture in horizontal or vertical concrete silos or below 50% moisture in oxygen-limiting silos limits the degree of compaction possible, and increases the probability of heat damage and of producing a silage with a shorter bunk life. This problem can be particularly acute with silages made from hollow-stemmed cereals, which may require the addition of water at ensiling time to get adequate compaction.

There are moisture meters available for on-site determination of moisture content of forage, but individual instruments should be thoroughly tested before being purchased. A simple hand test and experience can be reliable criteria for assessing forage moisture content.

A handful of chopped forage squeezed into a ball will respond differently, depending on its moisture content.

Forage ball	*Approximate percentage of moisture*
Holds shape; considerable free water	Over 75
Hold shape; very little free water	70–75
Falls apart slowly; no free water	60–70
Falls apart rapidly	Below 60

Ensiling equipment

Forage harvesters may be equipped to pick up a previously cut swath or to direct-cut and chop the forage, using a cylinder-type cutting head, and to blow the chopped material into a following wagon or truck or into an attached trailer. Other types include radial knives and flail chopping devices, which do not provide as uniform a cut and may plug more easily. Radial knives are inconvenient because they have to be removed for sharpening. Power requirement is relatively high for all types. A medium-sized forage harvester requires a 70-kW (95-hp) tractor to drive the power take-off and pull the harvester and storage wagon. Harvesting rates vary between 10 and 14 wet tonnes (4–6 t dry matter) of grass–legume silage per hour, depending on forage yield and field conditions. In chopping grass, legume, or cereal silages it is important to note that the drier the material the finer the chop should be in order to get adequate compaction.

Once chopped, forage boxes of various sorts can be used to transport the chopped forage to the silo. They can be truck or trailer mounted and equipped with a live bottom or a dumping mechanism. The wagons require 22–37 kW (30–50 hp) to pull them, depending on soil conditions and topography. The uniform distribution and packing of the chopped forage are essential regardless of the type of structure. In large tower silos, blowers equipped with a distributor uniformly fill the silo and the weight of the silage packs it. Smaller tower silos benefit by packing. Never enter a silo that is partially filled without first running the blower for at least 30 minutes to drive out toxic gases. A skillful operator and a tractor equipped with a roll bar and dual tires are necessary to pack silage in horizontal silos. Well-packed silage should feel firm underfoot and not spongy.

Silage is removed from silos by a variety of procedures. Tower silos are often unloaded by top unloaders. A suspended rather than a surface riding model is preferable in areas where heavy frost occurs. The unloader must be equipped with chipping wheels and a leveling mechanism when working with frozen silage. An ohm meter assists the operator in keeping an unloader operating efficiently without overloading the motor. Bottom unloaders facilitate continuous-feeding systems, because feeding can continue while the silo is being filled. They are expensive to repair and do not function properly if silage is below 30% dry matter.

Horizontal silos may be unloaded with a sturdy front-end loader bucket, preferably equipped with a grapple fork. Care should be taken to keep the face of the silage tight. Commercial unloaders that are designed to cut vertical slices of silage and blow it into a forage box but leave the face of the silage firm cause less wastage than other feeding-out procedures. Horizontal silos allow the flexibility of self-feeding, using either an electric fence or feeding gate to control the cattle. A self-feeding system reduces equipment and energy requirement and if properly managed is the most efficient system for utilizing the silage. Self-feeding horizontal silos should be sheltered from snow and rain, and should have a concrete floor and apron so that manure can be scraped away to an accessible storage area.

A mechanized system is generally used to feed silage to livestock. This system may either be in the form of a self-unloading mixing wagon, or truck, or a mechanical bunk feeder, or a combination of both. A mixing wagon provides an effective means of incorporating grain or supplements into a forage ration and can be equipped with scales, which allow for the accurate formulation of complete feeds. This system also allows silage to be fed at locations that cannot be serviced by a conveyor system.

A mechanical feed bunk may be used in conjunction with a tower silo. A screw conveyor, or auger, is an appropriate mechanism, although that system will not move long hay or straw and has a high requirement for power compared to other systems such as chains, paddles, and oscillating or vibrating conveyors.

Silages as feedstuffs

Grass and legume silages Legumes generally tend to be low in soluble carbohydrate content and have a high buffering capacity. Crops such as alfalfa should be ensiled with acid-producing additives or should be grown and ensiled as grass–legume mixtures. The preservation of grass and legumes as silages results in a reduction in feeding value when compared with fresh grass. This depreciation in feeding value is partly through effects on voluntary intake and partly through a wastage of nutrients by the metabolic conversions that occur during the fermentation process. As happens when forage is preserved as hay, nutritive value and voluntary intake drop sharply if there is a reduction in quality during the preservation process. It is more difficult to estimate visually the quality of silage than of hay. The identification of the appropriate chemical analyses that will assist in the estimation of silage quality is a major requirement. Dry matter content should be corrected for loss of volatile compounds. Acid detergent fiber and lignin contents are used to estimate maturity and digestibility, and various nitrogen fractions can be used to estimate heat damage. These chemical parameters can all be used to predict the nutrient value of silages.

The intake of silages has been correlated with silage dry matter content, pH, ammonia concentration, and total acidity, but consistent relationships have not been reliably measured. Partial neutralization with sodium bicarbonate at feeding time has improved intake of corn silages but not of grass or legume silages. As with other methods of forage preservation, silages with low levels of protein or phosphorus will not be consumed as readily or digested as completely as silages with adequate levels of those components.

In comparing the feeding value of silages to hay (weight per weight) the major difference is in water content. Hay has only 10–15% moisture (85–90% dry matter), whereas silages range from 50 to 80% moisture (20–50% dry matter). Therefore one must feed up to five times as many kilograms of silage to obtain an intake of dry matter that is equivalent to the amount of hay fed. For example, 10 kg of hay containing 10% moisture would provide 9 kg of dry matter, whereas a total of 45 kg of silage containing 80% moisture would have to be fed to provide the same quantity of dry matter. Numerous research findings have shown that dry matter intake rises by about 1% for

each 1% increase in the dry matter content, at least in silages containing between 15% and 35% dry matter. The intake increases very little for silages with a higher dry-matter content. However, as the dry matter of forages increases, their digestibility falls slightly; forages with a higher moisture content are often more digestible because they are less mature.

The quantity of grain added to silages generally has a positive effect on total intake and milk yield. The data presented in Table 5 are based on results from the Agassiz Research Station and the Animal Research Centre in Ottawa. The table shows how choice of forage and grain intake affect milk yield.

TABLE 5 The intake of grass and legume silages by lactating cows

Type of silage	Dry matter %	Protein %	Silage DM intake kg/day	Grain DM intake kg/day	Milk yield kg/day
Sorghum sudan grass	23.0	8.5	9.2	4.7	17.2
Alfalfa	27.8	19.3	9.9	4.8	21.3
Orchard grass	21.8	16.0	11.1	9.6	28.7
Rye grass	22.2	12.8	9.2	9.2	27.6
Orchard grass and white clover	22.6	19.6	13.0	6.2	25.0

Grass, grass legume, or legume silages are suitable for all classes of ruminants over 6 months of age.

Cereal silages It is convenient for many livestock producers to harvest cereals as silages. Cereals are different from grasses and legumes in that, with the exception of oats, maximum quality occurs when the grain is approaching maturity. Care has to be taken to properly ensile cereals, because the moisture content may be low. Fine chopping and careful packing are essential. During the ensiling process, water should be added to assist compaction if the dry matter exceeds 40% in a bunker silo or 50% in a tower silo.

The protein of cereal silages is generally lower than the protein content of grasses, and in terms of the supplements required cereal silages should be treated in the same manner as corn silage. Special attention has to be given to the addition of protein and calcium to a ruminant ration based on cereal silage. The digestibility, or feeding value, of cereal silage depends on the amount of straw that is included with the head when it is chopped. The basic purpose of cereal silage is to maximize dry matter yield by utilizing the whole plant, while at the same time reducing the harvesting of grain and straw to one operation. There is a tendency with many feedlot operators to use head chop silage. Head chop barley is usually harvested at the medium dough stage

of maturity. The ensilage will have approximately 50% dry matter in the form of 50% kernels and 50% chaff and straw by weight. Crude protein content may be as high as 13%, depending on type of growing season and variety grown. Cereal silage can result in excessive weight gains in dry cows and replacement heifers. A number of feeding trials with cereal silages were done at the Animal Research Centre and a brief summary of the results are provided in Table 6. The Department of Animal and Poultry Science at the University of Saskatchewan has also conducted a number of studies on cereal silages and those results are summarized in Appendix B.

The intake of cereal silages by dairy cows varied with the quality of silage, the amount of grain fed, and the level of production, but generally speaking the firm dough stage of maturity provided the highest energy intake. It should be remembered that winter wheat is low in protein and that protein content of cereals decreases with increasing maturity; therefore appropriate supplements are required.

Conclusions

Improved ensiling procedures and mechanized feeding systems have made the preservation of forages as silage a popular means of using grass, legume, and cereal crops.

Compared with haymaking, ensiling reduces wilting time and the risk of field losses, but it generally involves higher machinery and storage costs.

Among the various structures available for storing silage are conventional concrete tower silos, concrete or steel oxygen-limiting tower silos, horizontal bunker silos, and polyethylene-covered stacks. Generally, the most expensive structures (oxygen-limiting silos) best preserve the quantity and quality of forages. It is important to check whether the increased value of the forage justifies the additional storage costs.

Additives give variable results and are not necessary when ensiling is done properly. Crops should be cut at optimum maturity, wilted to 30% or 40% dry matter (for hay crops) or moistened, if necessary (for drier whole cereals), and finely chopped. The silo should be filled quickly, then carefully sealed. In rainy areas where wilting is difficult, the addition of formic acid is the best way of storing high-moisture silage.

The feeding value and chemical characteristics of silage are variable, depending on the type of forage and fermentation process. To obtain maximum benefit from feeding silages, quality should be monitored by standard laboratory procedures and appropriate supplements used in conjunction with silage feeding programs.

TABLE 6 **The dry matter intake, acid detergent fiber, protein, and digestibility of cereal silages**

Cereal	Dry matter %	Dry matter intake kg/day	Acid detergent fiber %	Protein %	Digestibility		Milk yield kg/day
					DM %	Protein %	
Oat silage							
milk	31.9	10.1	33.5	14.4	64.8	67.0	18.2
soft dough	36.6	11.6	34.2	10.5	58.5	62.2	19.4
Winter wheat							
milk	32.6	13.2	34.5	8.3	55.8	54.5	15.2
soft dough	38.5	13.1	30.3	7.0	53.7	51.6	14.8
firm dough	40.2	14.0	27.4	7.2	56.6	53.2	15.9
Triticale	33.1	9.3	32.5	12.8	56.6	—	21.4
Barley							
milk	22.8	9.7	26.4	16.4	59.4	—	18.7
soft dough	30.8	11.0	28.0	11.3	59.0	—	17.9
firm dough	45.8	10.6	30.2	9.8	55.9	—	18.5
Rye, preheading	23.9	7.4	43.4	8.5	53.0	46.1	14.6

APPENDIX A

Annual costs for storage of 168 t of potential dry matter in the field

Costs	Concrete oxygen-limiting tower silo 6 × 21 m	Conventional concrete tower 6 × 21 m	Bunker silo 9 × 36 × 3 m
	$	$	$
Silo	45 000.00	30 000.00	15 000.00
Unloader	15 000.00	7 000.00	4 000.00
Annual capital cost (12%/yr)*	7 200.00	4 440.00	2 280.00
Unloader maintenance (4%/yr)	600.00	280.00	160.00
Total annual cost per tonne of dry matter	46.43	27.86	14.52
Field losses	10%	8%	8%
Storage losses	5%	10%	15%
Cost of losses per tonne of potential dry matter ($80/t)†	12.00	14.40	18.40
Unadjusted annual cost (dollars per tonne of dry matter)	58.43	42.26	32.92
Use factor‡	1.5 times	1.25 times	1.25 times
Annual cost adjusted for use (dollars per tonne of dry matter)	38.95	33.81	26.34

* Annual capital cost is calculated according to the following annuity formula:
$i(1+i)^n / [(1+i)^n - 1]$. Here we assumed a period of 20 years ($n = 20$) and an interest rate of 10% ($i = 0.10$).

† Forage value is given in dollars per tonne of dry matter. A value of $80/t of dry matter is equivalent to $64/t of hay at 20% moisture, to $40/t silage at 50% moisture, and to $16/t of silage at 80% moisture.

‡ The use factor is the number of times that a silo can be filled per season.

APPENDIX B

Summary of nutritive value of cereal silages

		Silage composition as percentage of dry matter					
	Percentage of dry matter	Crude protein	Ash	Lignin	Neutral detergent fiber	Acid detergent fiber	Voluntary intake kg/day
BARLEY							
Bonanza	31.2 (22.7–35.2)*	13.1 (12.0–15.2)	8.1 (7.9–8.3)	6.4 (4.7–7.5)	58.2 (57.4–59.0)	30.4 (25.2–34.4)	4.2 (2.2–5.9)
Hector	31.0	14.3	—	—	—	—	4.3
WHEAT							
Fielder	52.6	10.7	—	—	—	33.1	4.7
Glenlea	39.4 (37.9–41.3)	13.0 (12.4–13.3)	6.8 (6.7–6.9)	7.8 (6.9–8.8)	56.5 (52.3–60.8)	32.7 (29.7–35.9)	4.5 (3.5–5.0)
Lenhi	39.1	13.1	5.9	8.0	53.7	35.1	2.9
Neepawa	43.5 (41.9–45.0)	12.7 (12.4–13.0)	— —	— —	— —	33.0 —	5.4 (5.3–5.5)
Pitic-62	37.9 (37.2–38.6)	12.7 (11.9–13.4)	7.6 (6.5–8.7)	6.8 (6.4–7.3)	55.0 (54.8–55.1)	33.7 (33.3–34.1)	2.7 (2.3–3.0)
Sinton	44.2	11.1	—	—	—	37.7	3.3
Wascana	38.4 (37.2–39.6)	12.8 (12.7–12.9)	7.2 —	7.5 —	58.2 —	35.1 —	3.3 (2.3–4.3)

APPENDIX B

Summary of nutritive value of cereal silages (concluded)

	Percentage of dry matter	Silage composition as percentage of dry matter					Voluntary intake kg/day
		Crude protein	Ash	Lignin	Neutral detergent fiber	Acid detergent fiber	
OATS							
Fraser	36.5	11.0	7.8	7.0	57.1	31.2	4.3
	(33.9–37.8)	(10.4–11.6)	(7.4–8.2)	(6.5–7.5)	(52.1–62.2)	(31.1–31.2)	(3.4–5.1)
Hudson	43.0	11.0	—	—	—	32.1	4.9
Random	40.1	11.3	—	—	—	32.8	5.2
	(36.4–43.7)	(10.8–11.7)	—	—	—	—	(5.1–5.2)
1863-4	36.5	10.8	6.0	7.9	52.9	33.3	4.1

* Indicates range of value observed.

Data courtesy of D. A. Christianson and G. M. Stacey, Department of Animal and Poultry Science, University of Saskatchewan. 1981.

APPENDIX C

Approximate dry matter capacity (tonnes) of tower silos

	Diameter m										
Height m	3.0	3.7	4.3	4.9	5.5	6.1	6.7	7.3	7.9	8.5	9.1
6.1	7	11	14	19	24	30	36	43	51	59	67
7.3	10	14	19	24	31	39	47	55	66	76	88
8.5	12	17	24	32	40	48	58	69	82	94	108
9.8	14	21	29	37	47	59	71	84	99	115	132
11.0	17	25	34	44	56	69	84	99	117	136	156
12.2	20	29	40	52	65	81	97	115	136	157	180
13.4		34	45	59	74	92	112	133	156	181	208
14.6		38	51	67	84	104	127	151	177	205	236
15.8			58	75	95	117	142	169	199	230	264
17.1			64	84	106	131	158	188	220	256	294
18.3			71	92	117	144	174	207	248	280	324
19.5					129	158	190	227	270	308	355
20.7					141	172	207	247	294	336	386
21.9								266	318	363	416
23.2								285	341	387	444
24.4								303	356	413	472

Note: Capacity is calculated to allow 0.3 m settling for the top 10 m and 1 m settling per 10 m depth for all silage underneath.

To calculate the total wet mass, the dry matter is multiplied by the factor [100/(100 − mc)] where mc is the moisture content on a wet basis (%).

Source: American Society of Agricultural Engineers Yearbook, St. Joseph, Michigan. 1983.

APPENDIX D

Approximate dry matter capacity (tonnes) of packed horizontal silos

Silo width m	Silo wall height m	Silo length m				
		20	24	30	36	50
9	3.0	96	119	153	187	266
	3.6	117	145	188	231	331
	4.2	137	172	224	276	398
12	3.0	129	159	204	249	355
	4.2	183	230	299	369	531
	5.4	237	301	399	496	723
15	4.8	263	332	435	539	781
18	4.8	315	398	523	647	937

To calculate the total wet mass, the dry matter is multiplied by the factor [100/(100 − mc)] where mc is the moisture content on a wet basis (%).